A Thin Window of Ti (6Al_4V) for Linac Momentum Dump

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Jan 25, 2011

A thin titanium window, used in linac Momentum Dump, will be subjected to both a vacuum load and thermal heating. This calculation is to estimate the temperature rise and stress due to the both structural and thermal load. The Fermilab –TM-1380, "Mechanical Safety subcommittee guideline for design of thin windows for vacuum vessels" by Jeff Western, will be used as a guideline.

Beam Energy Deposition

Table 1 Energy Deposition in Ti Widow
Provided by S.D Reitzner (1/12/2011)

Diameter (inches)	Thickness (mils)	dE Beam Spot (GeV/g)	dE Outside of Beam Spot (GeV/g)
6	5	$(3.407\pm0.017)\times10^{-4}$	$(1.63\pm0.73)\times10^{-8}$
8	5	$(3.427\pm0.020)\times10^{-4}$	$(0.50\pm0.15)\times10^{-8}$
6	10	$(3.424\pm0.015)\times10^{-4}$	$(0.49\pm0.18)\times10^{-8}$
8	10	$(3.422\pm0.014)\times10^{-4}$	$(0.77\pm0.29)\times10^{-8}$
6	15	$(3.454\pm0.014)\times10^{-4}$	$(1.52\pm0.74)\times10^{-8}$
8	15	$(3.466\pm0.014)\times10^{-4}$	$(0.73\pm0.21)\times10^{-8}$

If we use the 3.466e-4 (gev/g) as maximum number, for 3 cmx3cm grid (Reitzner's simulation):

thickness, inch		DV cm^3	DE (gev/gram)	Dens (g/cm^3)	E(gev) for each proton
0.01	0.0254	0.2286	3.47E-04	4.43	**3.51E-04**
0.015	0.0381	0.3429	3.47E-04	4.43	**5.27E-04**

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For Operation case, it will be **1.2E12** proton/pulse, and **7.5E12 proton/pulse for accident case**. Then we'll have

Gev/pulse	jole/pulse	pulse/sec	(jole/sec)			
4.21E+08	6.75E-02	15	**1.01 w**	for 10 mils_OP	**6.31 w**	for accident case
6.32E+08	1.01E-01	15	**1.52 w**	For 15 mils_OP	**9.5 w**	for accident case

Window temperature rise

A FEA model as shown in Fig 1 is used to calculate the window temperatures. The beam spot area is assumed to be 1.5 cm in diameter. It is twice smaller than 3 cm x 3 cm grid form Reitzer's simulation. However, total energy stays the same as 1.01 w for 10 mils window and 1.52 w for 15 mils window, respectively. The result is summarized in Table 2

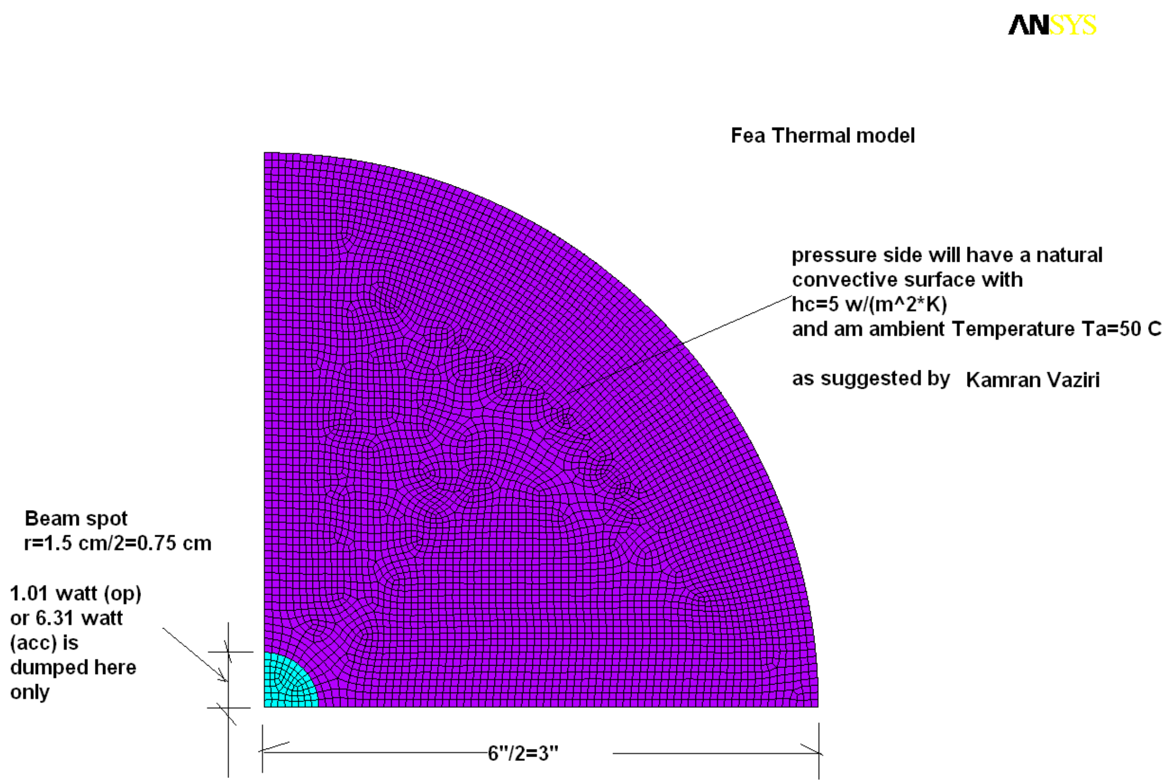


Fig 1 The FEA model for the temperature profile

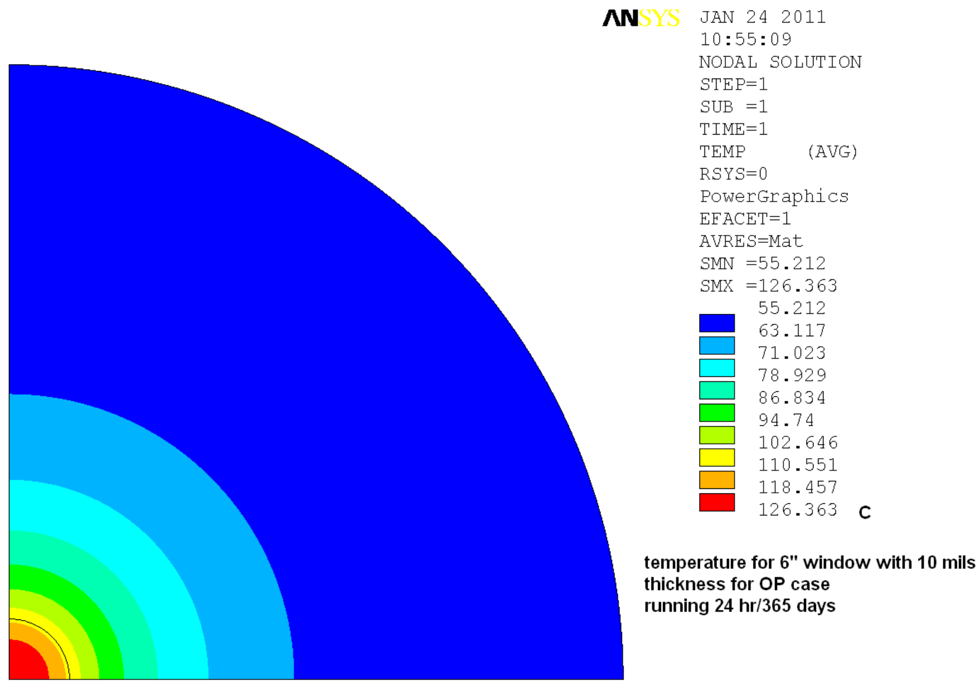


Fig 3 The temperature rise for a 6" window, 10 mils,OP

Table 2 Temperature rise for the Window (C)

	10 mils	15 mils	10 mils (accident)	15 mils (accident)
6" window	126 C	135 C	527 C	585 C
8" window	125 C	133 C	522 C	573 C

Window Stress

To calculate the stress due to the both vacuum load and thermal gradient, a shell element model is used. Both membrane and membrane+bending approach have been tried. The " membrane+bending" give a slightly high stress. Therefore, that approach is used. The result is summarized in Table 3

Table 3 The stress for operation case

	Vacuum load (15 psi)	Vacuum + thermal	Ultimate tensile strength around 130 ksi at 135 C
6"_ 10 mils	31 ksi	29 ksi	
8"_ 10 mils	37 ksi	35 ksi	
6"_15 mils	25 ksi	23 ksi	
8"_15 mils	29 ksi	28 ski	

Note

For operating temperature of 135 C, Ti (6sl-4v) has a ultimate tensile strength of ~130 ksi. Fermilab thin widow standard requires SF=2 as min. The Table 3 shows that we have almost SF>3.5 which should be sufficient.

Table 4 The stress for an accident case

	Vacuum load (15 psi)	Vacuum + thermal	Ultimate tensile strength around 80 ksi at an elevated temperature
6"_ 10 mils	31 ksi	26.8 ksi	
8"_ 10 mils	37.1 ksi	33.3 ksi	
6"_15 mils	24.9 ksi	25.18 ksi	
8"_15 mils	29.1ksi	25.64 ski	

Note

For accident temperature of 585 C, Ti (6sl-4v) has a ultimate tensile strength of ~around 80 ksi at an elevated temperature. The Table 4 still shows that we have SF>2 even for an accident case up to 1 hour.

Conclusion

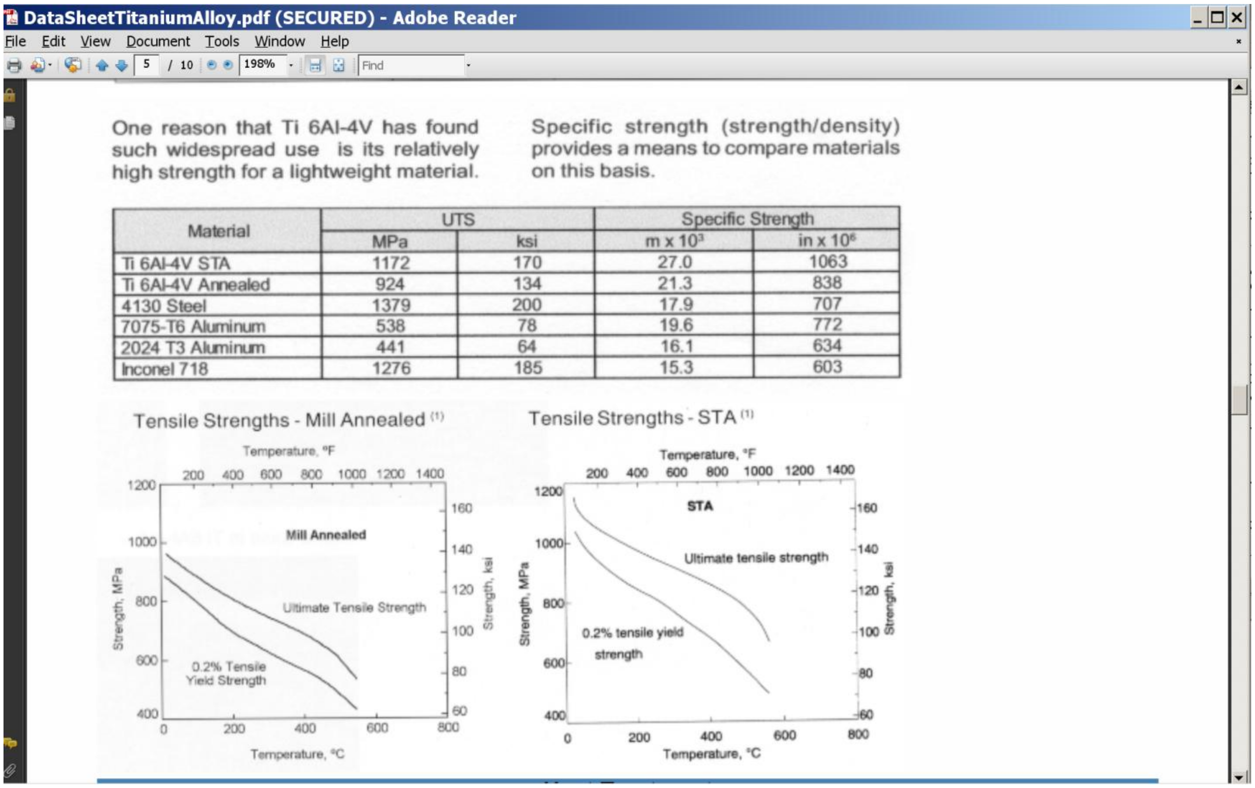
The Titanium has a tensile strength around 130 ksi at room temperature and ~80 ksi at the elevated temperature. The minimum safety factor (SF) is 2, required by Fermilab. It seems both 10 and 15 mils will satisfy that requirement for either 6" or 8" pipe. It is a simple and cost effective solution.

Reference

1) S.D. Reitzner," Ti Window Energy Deposition Results",1/12/2011
2) Jeff Western," Mechanical Mechanical Safety subcommittee guideline for design of thin windows for vacuum vessels", FEMILAB-TM-1380, March 1991.

Appendix

1) Ti property graph



DataSheetTitaniumAlloy.pdf (SECURED) - Adobe Reader

One reason that Ti 6Al-4V has found such widespread use is its relatively high strength for a lightweight material.

Specific strength (strength/density) provides a means to compare materials on this basis.

Material	UTS		Specific Strength	
	MPa	ksi	m x 10³	in x 10⁶
Ti 6Al-4V STA	1172	170	27.0	1063
Ti 6Al-4V Annealed	924	134	21.3	838
4130 Steel	1379	200	17.9	707
7075-T6 Aluminum	538	78	19.6	772
2024 T3 Aluminum	441	64	16.1	634
Inconel 718	1276	185	15.3	603

2) E mail message from Kamran Vaziri

----- Original Message -----

From: "Kamran Vaziri" <vaziri@fnal.gov>

To: "Diane Reitzner" <reitzner@fnal.gov>; "Ang Lee" <alee@fnal.gov>

Sent: Wednesday, January 12, 2011 5:03 PM

Subject: Temperature of the body of the absorber

Hi, Ang,

Assuming the body of the absorber, hence the nitrogen, are about 30 degrees C above the room temperature, should be

a good conservative assumption.

Cheers,

Kamran